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PILOT STUDY TO EVALUATE THE SQUEEZE TEST FOR USE IN VEHICLE-MOBILITY RESEARCH

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PREFACE

The study reported herein was suggested by the Army Mobility Research Center Board of Consultants, and was authorized under Corps of Engineers Subproject 8-70-05-400, Trafficability of Soils as Related to the Mobility of Military Vehicles. The study was planned and conducted by the Army Mobility Research Center, Soils Division, Waterways Experiment Station. The actual testing was done by personnel of the Soils Test Section, Embankment and Foundation Branch, Soils Division.

Mr. A. J. Green, Jr., directed the study under the general supervision of Messrs. W. J. Turnbull, C. R. Foster, and S. J. Knight, and prepared this report. Mr. J. E. Green assisted in the analysis of the data.

Directors of the Waterways Experiment Station during the conduct of this study and preparation of this report were Col. A. P. Rollins, Jr., CE, and Col. Edmund H. Lang, CE. Mr. J. B. Tiffany was Technical Director.

CONTENTS

NOTATIONS

Squeeze Tests

a = 1/2 specimen height, in.

a_o = 1/2 original thickness, in.

B = width of specimen, in.

c = shear strength, psi

e = strain, per cent

L = 1/2 specimen length, in.

n_x = lateral stress, psi

n_z = normal stress, psi

P = load, lb or kg

S = shear stress

x = distance along X-axis

X = horizontal axis

z = distance along Z-axis

Z = vertical axis

β = angle between a line tangent to the plane of maximum shear and the vertical axis Z-Z

γ_d = dry density, lb per cu ft

τ_{max} = maximum shear stress

Triaxial Compression Test

A_o = initial cross-sectional area of test specimen, sq in.

e = strain, per cent

h = height of specimen, in.

d = diameter of specimen, in.

P = applied normal load, lb

c = shear strength, psi

γ_d = dry density, lb per cu ft

$\theta = 45^\circ$ = angle of shear

σ_1 = major principal stress = normal stress at failure plus chamber pressure, psi

σ_2 = intermediate principal stress, psi

σ_3 = minor principal stress, psi

ϕ = angle of internal friction, deg

SUMMARY

The Jurgenson squeeze test was studied to evaluate its possible usefulness in vehicle-mobility research. The study included a comparison of the strength measurements obtained on two fat clays by means of the squeeze test, the unconsolidated-undrained triaxial compression test, and the cone penetration test. The average unconfined compression test shear strengths of 15 soils, taken from another study, are included for comparative purposes only. The squeeze test was easy to perform and did not require expensive equipment. Its results correlated well with the results of the other strength tests including cone penetrometer measurements. Data compiled in this study support the theory that the squeeze test determines the average strength of the soil, whereas the triaxial test measures the strength along the weakest plane. It is concluded that the squeeze test is suitable for initial inclusion in laboratory vehicle-mobility research programs. It is recommended that additional tests be performed in order to provide more data for correlation of squeeze test shear strength with cone index, and that the squeeze test be incorporated in a contemplated laboratory-scale vehicle testing program as an aid to the establishment of soil-vehicle interrelations.

PILOT STUDY TO EVALUATE THE SQUEEZE TEST FOR USE IN VEHICLE-MOBILITY RESEARCH

PART I: INTRODUCTION

1. In the field of vehicle-mobility research, wet, soft soils are of major interest since they provide the greatest difficulty for off-the-road traffic. Consequently, a test that will determine with reasonable accuracy the average strength and deformation characteristics of wet, soft soils is needed in the vehicle-mobility research program.

2. The Jurgenson squeeze test was selected for investigation of its suitability for this purpose because it will determine the average strength of soils so soft and wet that they flow under comparatively small loads. The test is based on a theory that appears reasonable and valid, and recognizes the plasticity of the material. Vehicles usually become immobile only when the soil flows from under them, causing them to sink considerably. Compression or consolidation unaccompanied by plastic flow seldom results in sinkage great enough to cause immobilization of a vehicle. Since the strength measured by the squeeze test may be applicable in theories of vehicle-soil relations, the test appears to be particularly suitable for use in vehicle-mobility research.

3. This report describes a preliminary study of the Jurgenson squeeze test made to: (a) familiarize personnel with the Jurgenson test, and (b) evaluate the possibility of using it in vehicle-mobility research.

4. The study consisted of a comparison of strength measurements obtained by means of the Jurgenson squeeze test, the unconsolidated-undrained triaxial compression test, the cone penetration test, and the unconfined compression test. The first three tests were actually performed for this study. However, the unconfined compression-test data were taken from TM No. 3-240, 1st Supplement,[9*] and used in this report to provide an additional comparison.

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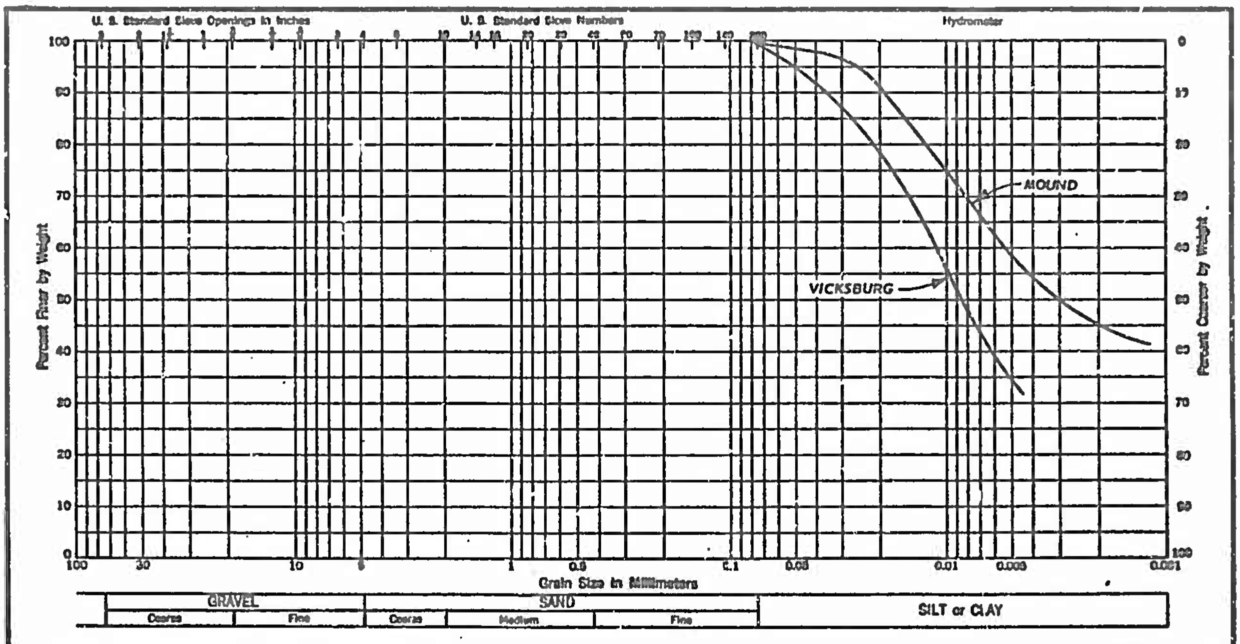
* Raised numbers refer to similarly numbered entries in the list of references.

PART II: SOILS TESTED AND TEST PROCEDURES

Soils

5. The two soils tested in this study were fat clays, both classed as CH according to the Unified Soil Classification System. One of the clays was found near Mound, Louisiana, and the other near Vicksburg, Mississippi. Gradation and classification data for the two soils are shown in fig. 1. Each soil was tested at moisture contents of approximately 29, 31, and 35%.



Location	L.L.	P.L.	P.I.	Classification
MOUND, LA.	61	22	39	FAT CLAY (CH)
VICKSBURG, MISS	58	21	37	FAT CLAY (CH)

SOIL GRADATION AND CLASSIFICATION DATA

Fig. 1. Gradation and classification data

Sample Preparation

6. A sufficient quantity of each soil to fill two molds 6 in. in diameter and 9 in. high (including a 2-in. collar) was thoroughly mixed

with a predetermined quantity of water to provide a set of two molds of each soil at each water content. One of the molds of each set was used to supply test specimens for the squeeze test and triaxial compression test; the other mold was used in the cone penetration test.

7. The soil in the molds was compacted by dropping a 5.5-lb hammer with a 2-in.-diam striking face from a height of 12 in. on each of five equal lifts. The compacted soil specimen was approximately 8 in. high. The soils with a moisture content of 29% were subjected to 22 blows of the hammer per layer, those with a 31% moisture content were subjected to 40 blows, and those with a 35% moisture content, 45 blows. The number of blows was varied in order to achieve three arbitrary levels of cone index: 130, 90, and 50. Previous compaction data from a soil similar to those in this investigation served as a guide in selecting the number of blows. After compaction, the molds were allowed to cure for 24 hours.

Squeeze Test

Equation used in test

8. The squeeze test was devised by L. Jurgenson, about 1934, to determine "the average strength of the material and not its strength along the weakest plane."[2] The equation for shear strength as used in this test

$$c = \frac{Pa}{BL^2\left(1 + \frac{\pi a}{L}\right)}$$

is based on theory for plastic flow; consequently, the equation is not valid at the beginning of the test when the plastic state has not yet been reached. (See Appendix A for derivation of the equation.) However, since ultimate shear strength is the prime consideration, the limitation upon the equation is not of enough importance to negate its significance. It should be noted that the original shear strength equation as developed by Jurgenson was later revised by a more reasonable assumption of stress conditions at the outer edge of the plate of the test apparatus.[4] The revised equation has been presented above and is used in the computations. This equation does not include the angle of internal friction, ϕ; therefore, the ultimate shear strength could be termed cohesion.

Test specimen

9. In the preparation of specimens of each soil at each water content for the squeeze test, the 2-in. collar was removed from the mold and the soil was trimmed flush with the top of the cylinder. The soil was then carefully extruded from the mold and a circular section 1 in. thick was cut from the top. A rectangle approximately 4 in. by 3 in. was then cut from the 1-in.-thick circular section. This rectangular specimen was subjected to the squeeze test.

Description of test

10. The squeeze test apparatus is shown in fig. 2. The test specimen is placed between two rigid plates; pressure is applied to the upper plate with a testing machine and the specimen is compressed between the plates. The teeth in the upper and lower plates are of 0.2-mm spring bronze with a 9-mm spacing; they project 1.5 mm into the sample in order to develop the shear strength of the material and to force the failure plane deeper into the soil. Average duration of the squeeze test in this study was less than 4 minutes. This short duration was intended to eliminate the possibility of consolidation which would retard or eliminate the occurrence of the plastic state in the soil. Sample failure is determined by the outward flow on two opposite sides of the plates (two sides are sealed). Deformation is determined by measuring the specimen thickness at time intervals throughout the test. In this study, load-deformation relations were ascertained by means of a continuously recording mechanism.

Triaxial Compression Test

11. The triaxial compression test is a conventional test in which the three principal stresses are known and controlled. It is performed on cylindrical specimens to determine stress-deformation and strength characteristics of the soil when subjected to lateral pressure. The major principal stress, σ_1, is equal to the sum of the applied axial load and chamber pressure. The intermediate principal stress, σ_2, and the minor principal stress, σ_3, are considered to be identical and are equal to the chamber pressure.

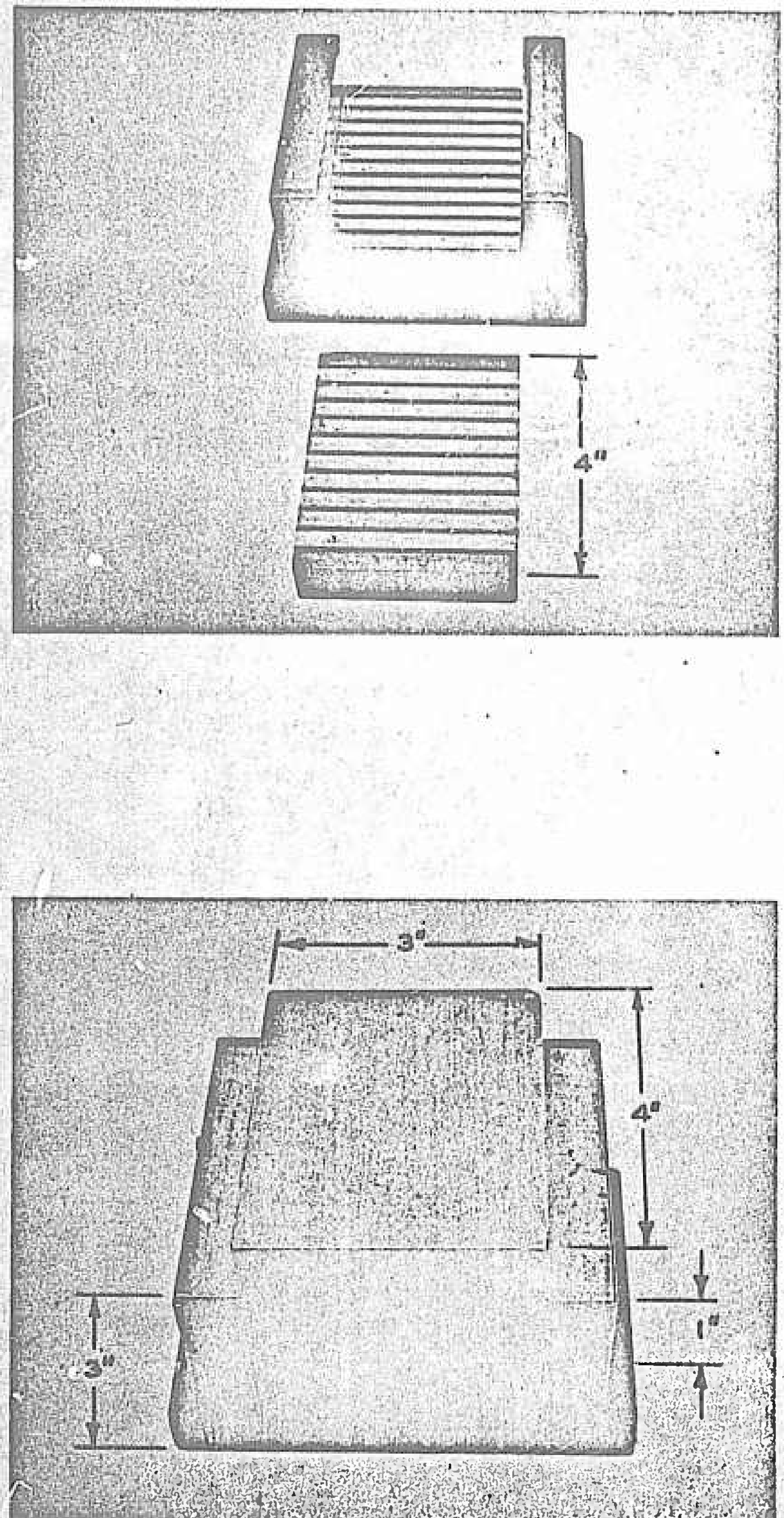


Fig. 2. Squeeze test apparatus

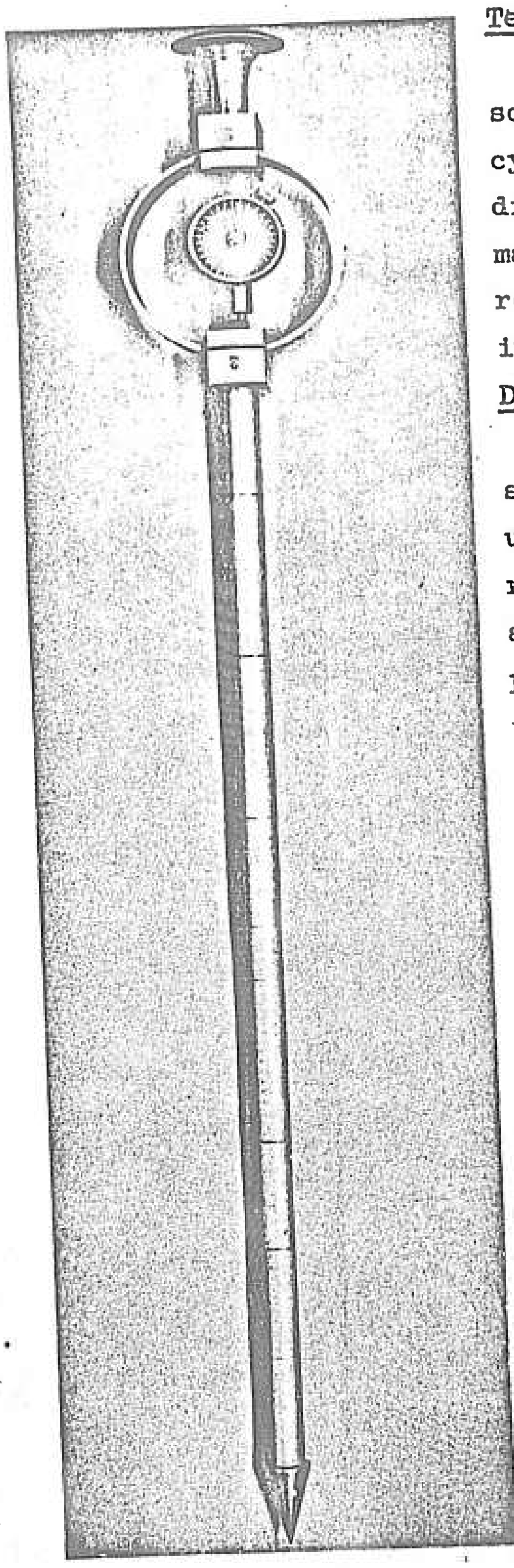


Fig. 3. Cone penetrometer

Test specimen

12. After the soil to be used in the squeeze test was removed from the mold, a cylinder of soil about 6 in. high and 6 in. in diameter remained. Three specimens approximately 3 in. high and 1.4 in. in diameter were removed from the top of this cylinder for use in the triaxial test.

Description of test

13. The triaxial test performed in this study was the standard unconsolidated-undrained compression test and is described in reference 8. Chamber pressures of 0.5, 1.5, and 3.0 tons per sq ft (6.94, 20.83, and 41.67 psi, respectively) were used. Durations of the test ranged from 7 to 8 minutes.

Cone Penetration Test

14. The cone penetration test is an empirical method of determining the strength of a soil, which has been used successfully in vehicle mobility and trafficability studies. Before the test was begun, the collar was removed from the remaining mold of each soil at each water content, and the soil was trimmed flush with the cylinder. Five penetrations were then made in each mold with a cone penetrometer having a right circular 30-deg cone with an end area of 1/2 sq in. (see fig. 3). The resistance of the soil to penetration of the cone in a slow downward movement was read at the surface of the molded sample, and at each inch of depth to 4 in. The readings, called cone index, were in pounds of force per square inch of end area of the cone.

PART III: DATA OBTAINED

Compaction Data

15. Table 1 shows the compaction data, wet and dry densities, and moisture contents of each of the 12 molds prepared. Wet density was determined by weighing the known volume of soil in the mold immediately before the sample was removed for the squeeze and triaxial tests (B molds), or immediately before the cone penetration test (A molds). At the same time, a representative sample was taken from the mold and used to determine the moisture content, with which the dry density was subsequently obtained.

Squeeze Test Data

16. Pertinent squeeze test data are shown in table 2. Moisture contents were determined from trimmings from the samples, and density values were obtained by weighing the test specimens. The load is shown for incremental strains from zero to beyond the failure point, and the shear strength is given in pounds per square inch for each increment. Original dimensions of the test specimens also are shown.

17. An example of a recording of the load-deformation chart is shown in fig. 4.

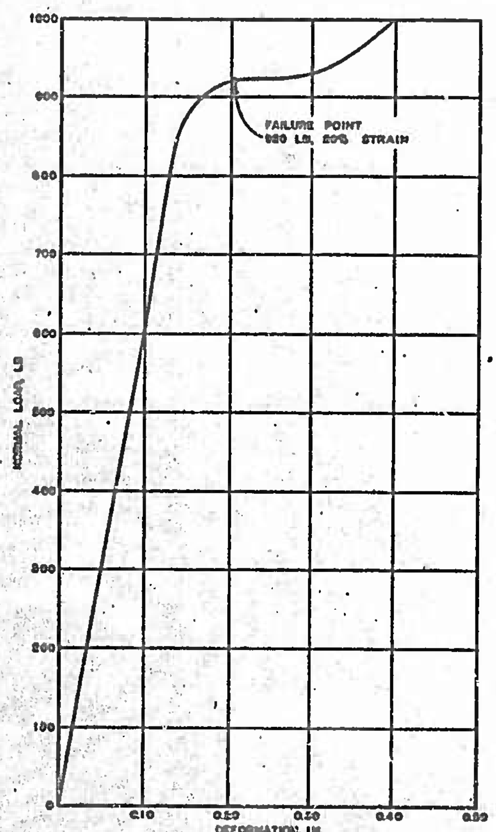


Fig. 4. Load-deformation chart, squeeze test, mold 1-B, Mound clay at 28.7% moisture content

Triaxial Compression Data

18. Data pertinent to the triaxial compression test specimens are shown in table 3. Moisture contents and densities

were measured in the same manner as in the squeeze test. The load is shown for incremental strains from zero to beyond the failure point. Since definite peak stresses were not obtained, 20% strain* was arbitrarily chosen as the failure point. A typical recording of the load-deformation chart is shown in fig. 5. Note that each curve begins at its own origin rather than

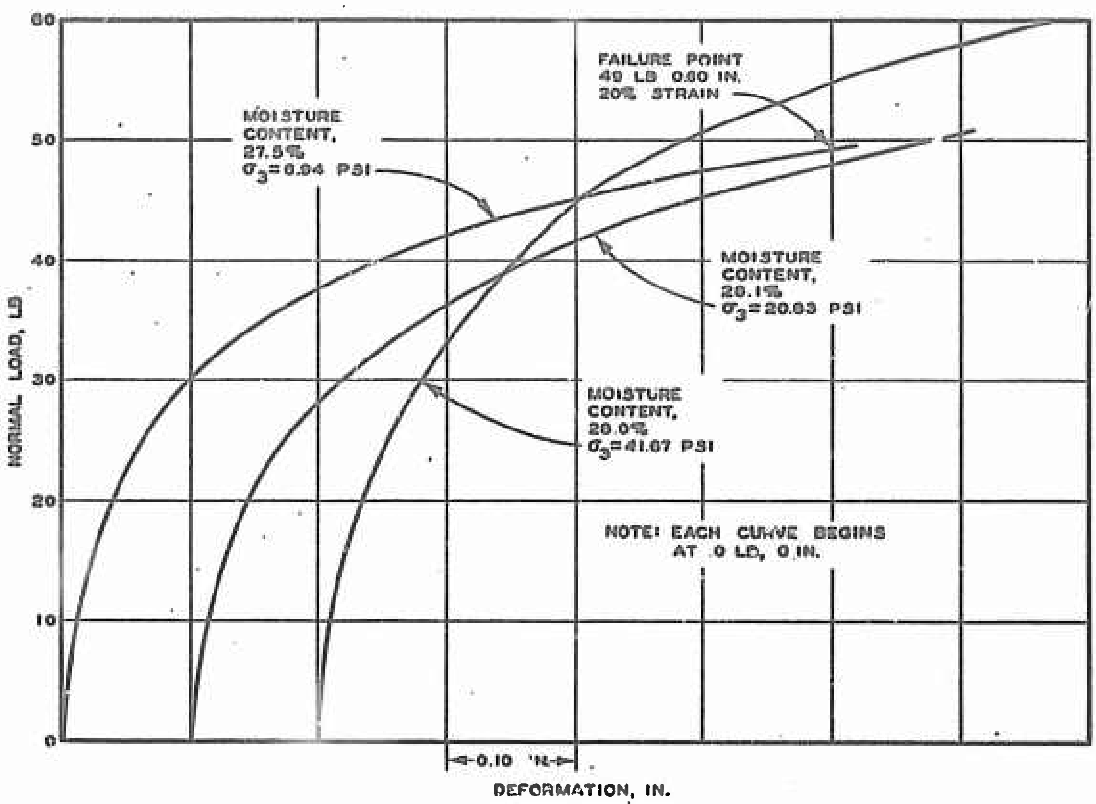


Fig. 5. Typical recording of the load-deformation chart

at a common origin. The soil is the Vicksburg clay at moisture contents of 27.5, 28.1, and 28% for samples under chamber pressures of 6.94, 20.83, and 41.67 psi, respectively. Mohr stress envelopes plotted for each series of triaxial compression tests are shown in plate 1. The angle of internal friction was not defined explicitly in each of these tests and the angles shown in the plate, which range from 1.0° to 3.3° were placed by eye to best fit the tangents to the circles. The plots in plate 1 indicate that the two clays, at these moisture contents, have practically zero angle of

* T. W. Lambe[5] suggests 15%; WES uses 20% in most cases.

internal friction. For this case the shear strength, which could be termed the cohesion, is $c = \frac{P}{2A_o}$. Table 3 shows the shear strength computed by this formula in pounds per square inch.

Cone Index Measurements

19. The average of five readings made with the cone penetrometer at the surface and at each inch of depth to 4 in. is shown for each mold, along with its moisture content and density, in table 4.

Unconfined-Compression Test Data

20. As stated in paragraph 4, no unconfined compression tests were performed in this study, but a curve from TM 3-240, 1st Supplement,[9] of cone index vs unconfined compressive strength provided a means of comparing unconfined-compression test data with squeeze test and triaxial test data obtained in this study. The curve, a visual average of data from many tests on each of 15 different soils, was developed from the average of cone index readings in a 2-in. depth of soil. Since the squeeze test and triaxial test data in this study were compared with averages of cone index readings in a 4-in. depth of soil, and the average for 4 in. was 18 cone index units higher than the average for 2 in., 18 cone index units were added to the curve so that the data would be comparable. The adjusted cone index and corresponding unconfined-compression shear strength, c , from reference 9 are given below.

Cone Index	Shear Strength c, psi
48	3.8
58	5.0
68	6.2
78	7.0
88	8.5
98	9.2
108	10.5
118	11.8
168	16.5

PART IV: ANALYSIS OF DATA

21. The data were analyzed by comparing plots of stress vs strain for the squeeze test and triaxial test; plotting the triaxial test shear stresses at failure against comparable values from the squeeze test; and plotting shear stresses at failure from the squeeze, triaxial, and unconfined compression tests against cone index.

Stress vs Strain

22. Shear stress-strain curves obtained from the squeeze test and the triaxial test (using three chamber pressures) on soil from the same mold are plotted in plates 2 and 3. Molds 1-B through 3-B (plate 2) contained Mound clay; molds 4-B through 6-B (plate 3) contained Vicksburg clay. Although the differences in the two tests were recognized, it was felt that the stress-strain relations from the tests would be of general interest. For the drier soils (molds 1-B and 4-B), the squeeze test shows lower shear strengths than the triaxial test below about 8% strain and higher strengths above 10% strain. The two types of curves are more similar to each other for the intermediately wet soils (molds 2-B and 5-B), and again the squeeze test strength is lower at low strains and higher at high strains. When the soils are very wet (molds 3-B and 6-B), the two types of stress-strain curves are very similar throughout the entire strain range with the squeeze test strength still slightly higher at the higher strains.

Shear Stresses at Failure

23. Plate 4 is a plot of shear stresses at failure for the Mound and Vicksburg soils determined by the squeeze test vs corresponding values as determined by the triaxial test on the same soil at the same condition. Failure is assumed to have occurred at 20% strain in all cases. A straight line through the origin with a slope of 0.825 (drawn by eye) fits the points fairly well. The equation for the mathematical straight line of best fit for the points shown is $z = 0.663x + 1.61$; the correlation

coefficient is 0.965, significant to the 1% level; and the standard error of estimate is 0.99. On the basis of the small amount of data obtained, it appears reasonable to conclude that the two curves correlate well with each other and that shearing strength determined in the triaxial test is probably from 66 to 82% of that determined by means of the squeeze test. The higher values obtained from the squeeze test support the theory that this test determines the average strength whereas the triaxial test measures the strength along the weakest plane. There is some slight evidence that soil type may influence the relation, but this evidence is not strong enough to justify the drawing of separate curves for the two soils.

Shearing Strength vs Cone Index

24. Plate 5 shows cone index plotted against shearing strength determined from the squeeze test (triangular symbols), from the triaxial test (circular symbols), and from the unconfined compression test (square symbols).

Squeeze test data

25. As stated earlier, the top 1 in. of soil from a mold, trimmed to the proper dimensions, was used for the squeeze test. The average values of cone indexes read at the 1-, 2-, 3-, and 4-in. depths were used in plotting cone index vs shearing stress at failure (20% strain). The six points (three for each soil) define a straight line reasonably well. The equation for the line of best fit is $z = 0.125x - 2.60$ (cone penetrometer reading is roughly 10 times the shear strength); the correlation coefficient is 0.969, significant to the 1% level; and the standard error of estimate is 1.33. A line through the points and also through the origin would not deviate widely from the mathematical line of best fit. Here again, there is some evidence that additional data might have defined a separate curve for each soil.

Triaxial compression test data

26. The average cone index values for the 1-, 2-, 3-, and 4-in. depths are plotted against triaxial shear strengths. A straight line appears to fit the data as well as any shape. The linear regression is $z = 0.094x - 1.12$; the correlation coefficient is 0.979, significant to

the 1% level; and the standard error of estimate is 0.774. The correlation between triaxial shear strength and cone index is slightly better than that between squeeze test shear strength and cone index. However, a line drawn by eye through the origin and the plotted points for both soils would be very close to the computed line of best fit.

Unconfined compression data

27. Cone index vs unconfined compressive strength is plotted in plate 5 using the data tabulated in paragraph 20. A straight line, determined by a linear regression analysis of the data, fits well through all the points. The equation of this line is $z = 1.107x - 1.123$.

Discussion

28. Soils that have a cone index greater than 100 in the remolded state are usually trafficable for any military vehicle. In vehicle-mobility research, therefore, the primary interest is in soils with lesser strengths, and in contemplated laboratory, scaled vehicle testing, soils having cone indexes below 100 will be of primary interest.

29. The squeeze test, though fairly easy to perform in a laboratory, would not be practicable as a trafficability test in the field where the character of the soil may vary widely in a given test area and a large number of tests would be necessary to determine the average soil strength of the area. Also, the squeeze test examines only one vertical inch of soil per test, whereas examination of at least 6 in. of soil is necessary in the field. To obtain this information with the squeeze test, it would be necessary to test six samples, which is not considered practical. Therefore, it is not likely that the squeeze test will supplant the cone penetration test as a trafficability field test, since the cone penetrometer is easy to use at any pertinent depth and provides a good, quick indication of soil strength without the necessity of obtaining a sample.

30. The squeeze test appears to have promise for vehicle-mobility research in the laboratory. It is relatively easy to perform and does not require expensive equipment. It correlates fairly well with the triaxial test and with cone index. Although the amount of data obtained in this study is probably too small to be conclusive, it appears that the squeeze

test results agree more closely with cone index at low soil strengths than at high soil strengths. Additional tests should be performed to determine whether this can be substantiated.

31. Squeeze test values of shear strength at failure are slightly higher than triaxial test values, and thus are believed to represent average rather than minimum soil strength. From trafficability studies, it appears that average values of soil strength are more suitable for correlation with vehicle performance than are minimum values. This is due to the vehicle's load being borne by a comparatively large area of the soil which tends to minimize the effect of variation in the soil under the vehicle and forces the soil to act as an average, homogeneous mass at any one instant.

32. Research on the shear strength of soils has shown that the speed with which a given soil is sheared has a noticeable effect on its strength.[7] It has been determined that the greater the speed of axial strain, the greater the shear strength. Little attention has been given to the difference in the speed of shear in the triaxial, unconfined compression, and squeeze tests reported herein; hence, the effect of this variable cannot be stated at this time. Additional testing should be performed in such a manner that the speed of shear will approximate that induced by vehicles.

33. Since the study reported herein was for exploratory purposes, only a small amount of testing was done. In view of the promising results, the study should be expanded, with emphasis on the soft soils that are of major interest. Since the correlations of the squeeze, triaxial, and unconfined compression tests with cone index were similar, it is suggested that the squeeze test be employed to a greater extent in future work in view of its simplicity, consistent results, and the possible use of the results in theoretical studies. It is believed that inclusion of the squeeze test in the contemplated scaled vehicle testing program where both the soil and vehicle component conditions will be closely controlled will supply an excellent opportunity to relate wheel and/or track performance to soil strength and deformation characteristics as well as to gain a better understanding of the soil action alone.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

34. Based upon the limited amount of testing performed in this study, the following conclusions appear warranted:

- a. The squeeze test affords a reliable measurement of soil strength and appears to be a suitable test for use in laboratory vehicle-mobility research.
- b. Squeeze test values of shear strength at failure are slightly higher than corresponding triaxial compression test values because the shear strength determined in the squeeze test is representative of the average strength of the sample, whereas the triaxial test determines only the strength of the weakest plane.
- c. The correlation between squeeze test shear strength and cone index was not significantly different from the correlation between triaxial test shear strength or the unconfined compression test shear strength and cone index.

Recommendations

35. In view of the promising results obtained in this study, it is recommended that tests be performed to provide additional data for correlation of squeeze test shear strength with cone index, and to investigate the deformation of soils under various conditions. The tests should include:

- a. Use of soil types varying from low-plasticity silts to highly plastic clays.
- b. A limited number of triaxial tests.
- c. Use of a consistent speed of shear approximating that induced by vehicles.

36. It is also recommended that the squeeze test be incorporated in the contemplated laboratory scaled vehicle testing program, on the premise that the squeeze test will afford an opportunity to relate vehicle performance to strength-deformation characteristics of soils.

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Table 1

Compaction Data

Mold No.	Blows Per Layer	Wet Density lb/cu ft	Dry Density lb/cu ft	Moisture Content %
		Mound Clay		
1-A*	22	107.6	83.6	28.7
1-B**	22	107.3	83.4	28.6
2-A*	40	113.7	87.0	30.7
2-B**	40	113.6	86.7	31.1
3-A*	45	111.9	83.1	34.7
3-B**	45	112.0	83.9	34.5
		Vicksburg Clay		
4-A*	22	109.5	85.6	28.1
4-B**	22	108.4	84.2	28.7
5-A*	40	115.6	88.5	30.7
5-B**	40	115.4	88.1	31.0
6-A*	45	112.0	83.4	34.4
6-B**	45	112.7	83.3	35.3

Note: Weight of hammer: 5.5 lb Hammer drop: 12 in.
Diameter of hammer face: 2 in. Number of layers: 5

* Used for cone index measurements.
** Used for squeeze and triaxial test specimens.

Table 2

Squeeze Test Data

Mold No.	Moisture Content %	Dry Density lb/cu ft	Sample Size in.	Load lb	Strain %	Shear Strength, c psi
			Mound Clay			
1-B	28.7	84.2	4 by 3 by 1.008	0	0.0	0.00
				310	5.0	7.06
				596	10.0	13.22
				860	15.0	18.36
				920	20.0	18.93
				925	28.0	17.82
2-B	31.3	88.2	4 by 3 by 1.008	0	0.0	0.00
				315	5.0	7.18
				550	10.0	12.14
				600	15.0	12.81
				618	20.0	12.72
				635	28.0	12.23
3-B	34.0	83.3	4 by 3 by 1.002	0	0.0	0.00
				167	5.0	3.79
				255	10.0	5.61
				282	15.0	6.00
				292	20.0	5.99
				300	23.5	5.98
			Vicksburg Clay			
4-B	28.1	85.0	4 by 3 by 0.976	0	0.0	0.00
				362	5.0	8.09
				630	10.0	13.65
				860	15.0	18.00
				915	20.0	18.46
				922	28.0	17.69
5-B	30.8	89.5	4 by 3 by 0.966	0	0.0	0.00
				270	5.0	6.00
				400	7.5	8.75
				495	12.5	10.48
				545	15.0	11.38
				560	20.0	11.22
6-B	34.3	83.4	4 by 3 by 0.976	0	0.0	0.00
				135	2.5	3.07
				195	5.0	4.32
				238	10.0	5.16
				252	15.0	5.28
				265	20.0	5.35

Table 3

Unconsolidated-undrained Triaxial Compression Test Data

Mound Clay

Mold No.	Moisture Content %	Dry Density lb/cu ft	Sample Size: Height in.	Sample Size: Diam in.	Sample Size: Area sq in.	At Failure: σ_1, psi	At Failure: σ_3, psi	Strain, e %	Shear Strength, c psi
1-B	28.1	86.9	3.002	1.342	1.415	31.95	6.94	0.0	0.0
								1.0	5.28
								3.0	9.10
								6.0	10.56
								10.0	11.32
								15.0	12.08
								20.0	12.50
	28.2	85.7	3.002	1.350	1.432	48.89	20.83	0.0	0.0
								1.0	5.97
								3.0	9.10
								6.0	11.32
								10.0	12.78
								15.0	13.61
								20.0	14.02
	28.1	86.1	3.002	1.385	1.506	69.17	41.67	0.0	0.0
								1.0	5.97
								3.0	9.79
								6.0	12.29
								10.0	13.13
								15.0	13.61
								20.0	13.75
2-B	30.7	89.0	3.002	1.377	1.489	26.11	6.94	0.0	0.0
								1.0	3.13
								3.0	5.21
								6.0	7.15
								10.0	8.54
								15.0	9.24
								20.0	9.58
	30.1	89.1	3.002	1.382	1.500	42.78	20.83	0.0	0.0
								1.0	4.03
								3.0	6.39
								6.0	8.33
								10.0	9.86
								15.0	10.28
								20.0	10.97
	30.2	89.9	3.002	1.379	1.494	64.17	41.67	0.0	0.0
								1.0	4.10
								3.0	6.25
								6.0	7.99
								10.0	9.51
								15.0	10.76
								20.0	11.25
3-B	33.9	84.9	3.002	1.358	1.448	17.78	6.94	0.0	0.0
								1.0	1.60
								3.0	2.71
								6.0	3.26
								10.0	4.44
								15.0	5.07
								20.0	5.[illegible]
	34.1	84.8	3.002	1.367	1.468	30.97	20.83	0.0	0.0
								1.0	1.67
								3.0	2.64
								6.0	3.49
								10.0	4.31
								15.0	4.79
								20.0	5.07
	34.2	85.4	3.002	1.354	1.440	53.34	41.67	0.0	0.0
								1.0	2.08
								3.0	3.13
								6.0	4.17
								10.0	4.93
								15.0	5.56
								20.0	5.83

Vicksburg Clay

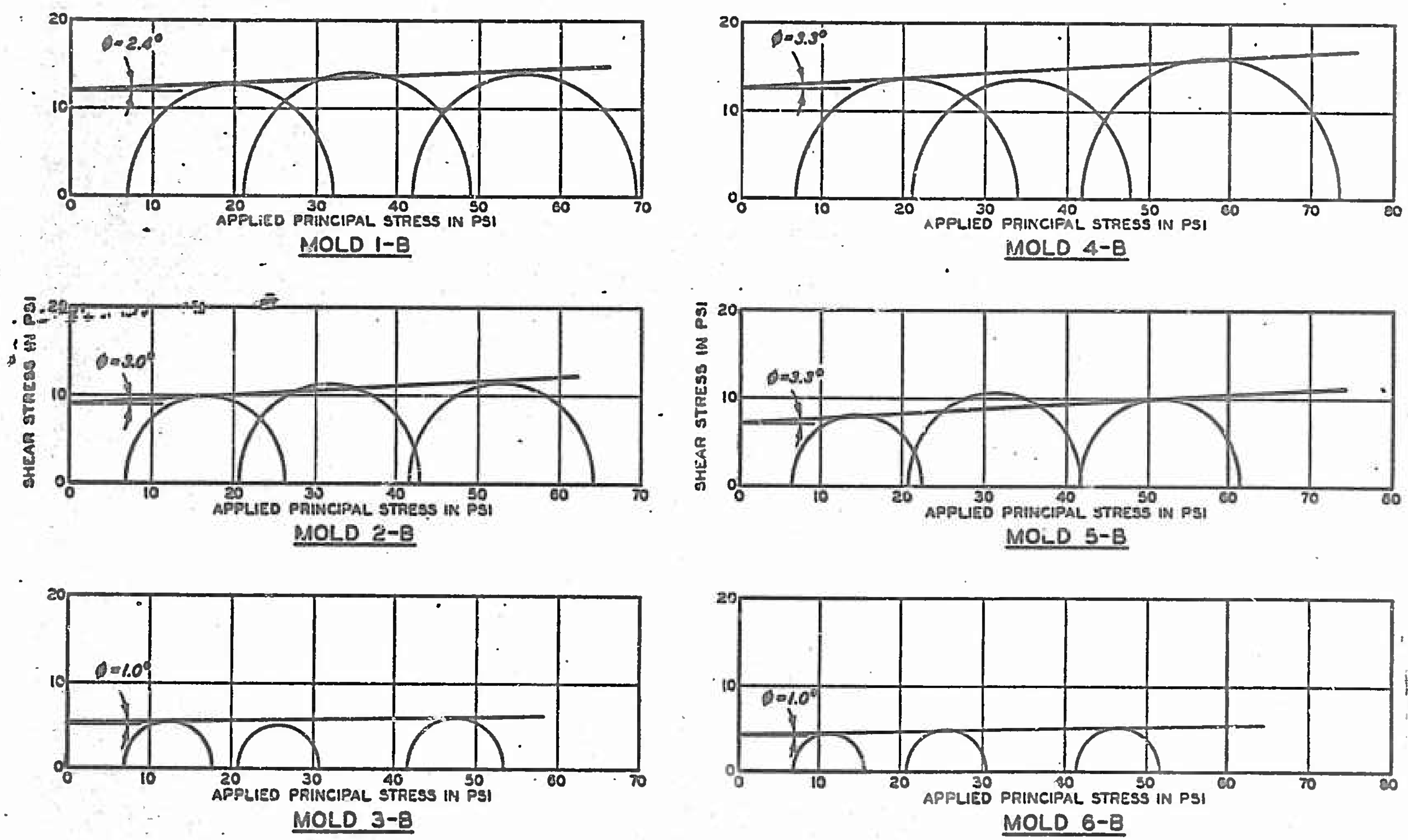
Mold No.	Moisture Content %	Dry Density lb/cu ft	Sample Size: Height in.	Sample Size: Diam in.	Sample Size: Area sq in.	At Failure: σ_1, psi	At Failure: σ_3, psi	Strain, e %	Shear Strength, c psi
4-B	27.5	87.9	3.005	1.390	1.517	32.92	6.94	0.0	0.0
								1.0	5.69
								3.0	9.45
								5.0	10.90
								10.0	12.57
								15.0	13.20
								20.0	12.92
	28.1	88.0	3.005	1.389	1.515	47.64	20.83	0.0	0.0
								1.0	4.93
								3.0	8.54
								5.0	10.28
								10.0	12.43
								15.0	13.26
								20.0	13.40
	28.0	87.8	3.005	1.389	1.515	73.89	41.67	0.0	0.0
								1.0	6.18
								3.0	10.21
								5.0	12.43
								10.0	14.31
								15.0	15.83
								20.0	16.11
5-B	31.0	88.5	3.010	1.330	1.389	22.36	6.94	0.0	0.0
								1.0	2.64
								3.0	4.51
								6.0	5.97
								10.0	7.01
								15.0	7.57
								20.0	7.71
	29.9	90.3	3.010	1.367	1.468	41.67	20.83	0.0	0.0
								1.0	4.51
								3.0	7.15
								6.0	8.89
								10.0	10.07
								15.0	10.35
								20.0	10.42
	29.7	90.3	3.010	1.376	1.466	61.67	41.67	0.0	0.0
								1.0	3.96
								3.0	5.97
								5.0	7.29
								7.0	8.06
								10.0	8.89
								15.0	9.65
								20.0	10.00
6-B	34.6	83.7	3.010	1.351	1.433	15.83	6.94	0.0	0.0
								2.0	2.08
								5.0	2.99
								7.0	3.65
								10.0	3.89
								15.0	4.31
								20.0	4.44
	34.2	83.3	3.010	1.346	1.423	30.70	20.83	0.0	0.0
								1.0	1.67
								3.0	2.92
								6.0	3.89
								10.0	4.57
								15.0	4.79
								20.0	4.93
	34.4	83.6	3.010	1.349	1.429	51.81	41.67	0.0	0.0
								1.0	1.60
								3.0	2.85
								6.0	3.75
								10.0	4.44
								15.0	4.72
								20.0	5.07

Table 4

Cone Index Data

Mold No.	Moisture Content %	Dry Density lb/cu ft	Depth in.	Cone Index*	Average Cone Index Sfc & 1 in.	2 to 4 in.	1 to 4 in.
				Mound Clay			
1-A	28.7	83.6	Sfc	113	123.0	146.7	143.2
			1	133			
			2	141			
			3	145			
			4	154			
2-A	30.7	87.0	Sfc	95	98.0	127.7	121.0
			1	101			
			2	111			
			3	123			
			4	149			
3-A	34.7	83.1	Sfc	45	52.0	71.3	68.2
			1	59			
			2	63			
			3	64			
			4	87			
				Vicksburg Clay			
4-A	28.1	85.6	Sfc	124	140.0	173.3	169.0
			1	156			
			2	170			
			3	175			
			4	175			
5-A	30.7	88.5	Sfc	82	90.0	130.3	122.2
			1	98			
			2	107			
			3	122			
			4	162			
6-A	34.4	83.4	Sfc	39	44.0	66.7	62.2
			1	49			
			2	55			
			3	63			
			4	82			

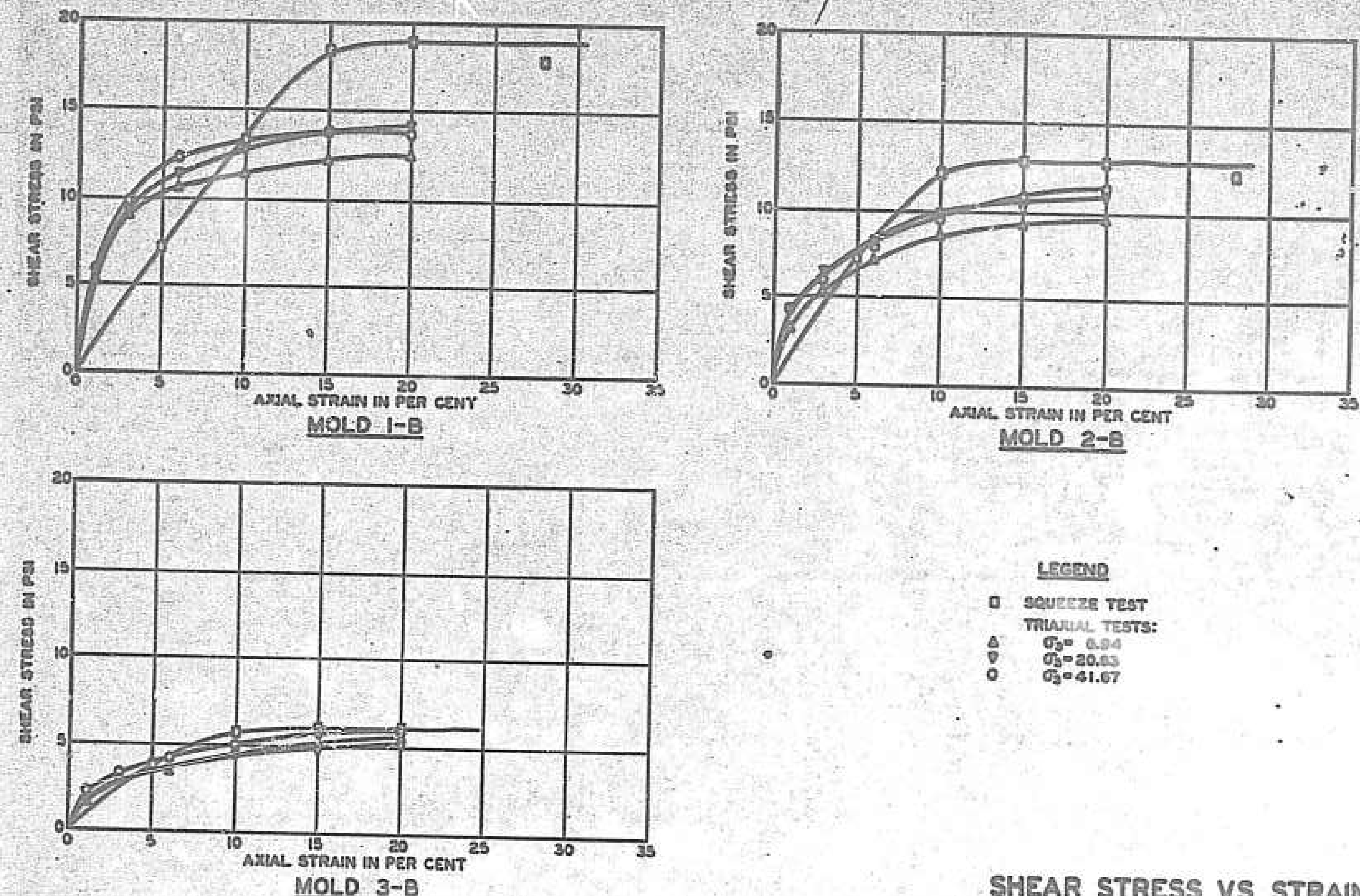
* Each value is the average of five readings.



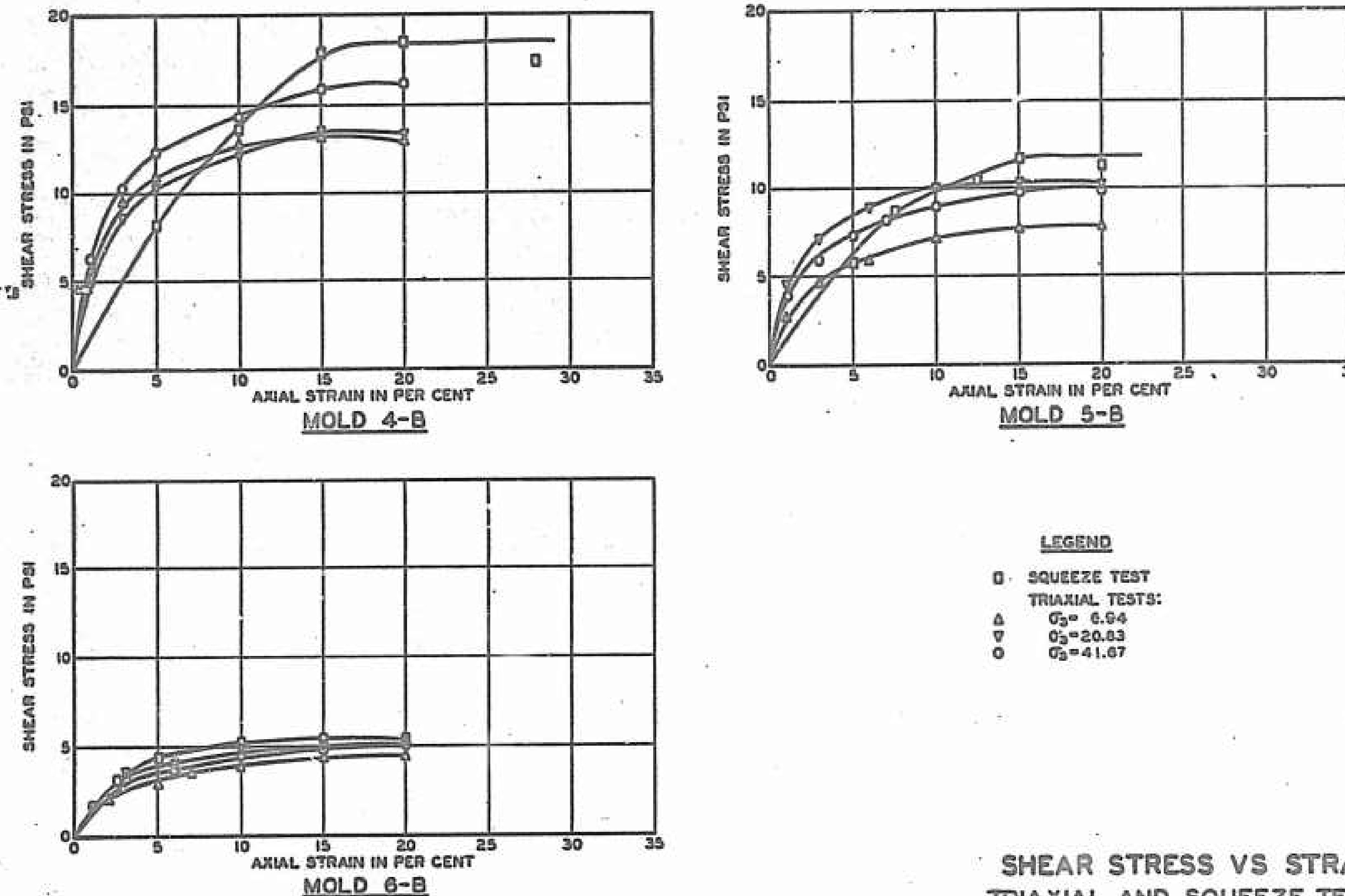
UNCONSOLIDATED-UNDRAINED
TRIAXIAL TESTS
MOHR STRESS ENVELOPES

PLATE 1

PLATE 2

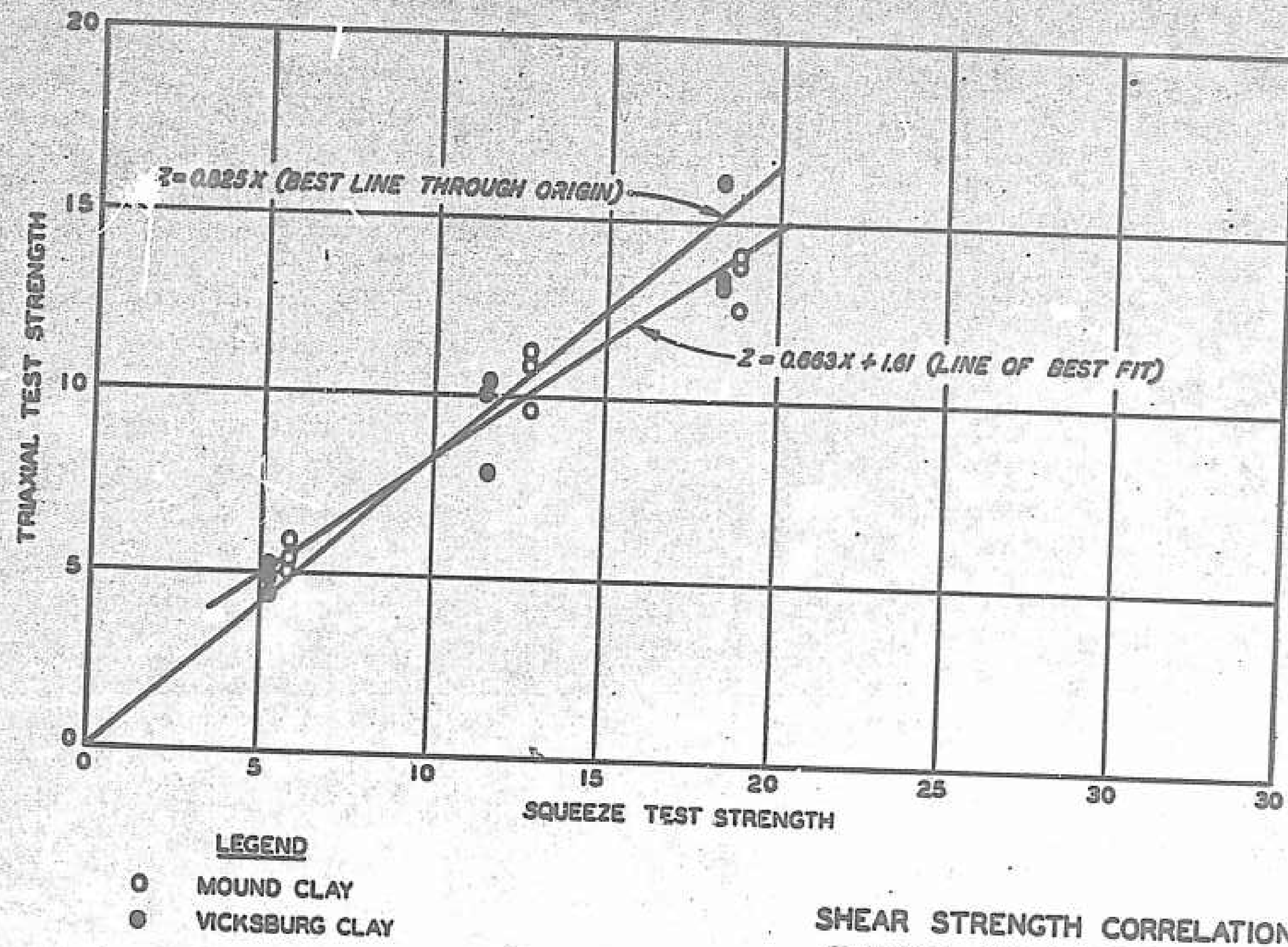


SHEAR STRESS VS STRAIN
TRIAXIAL AND SQUEEZE TESTS
MOUND CLAY

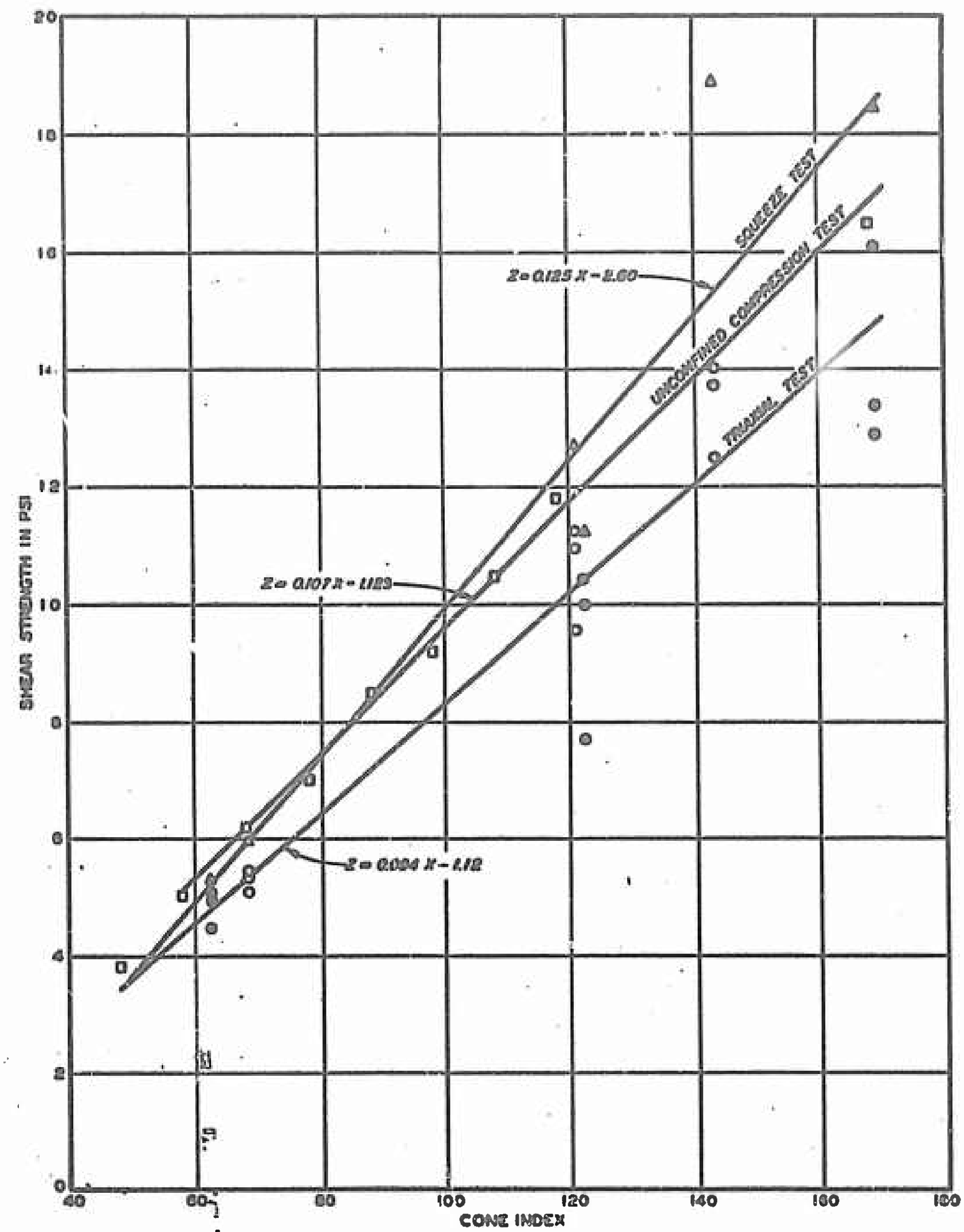


SHEAR STRESS VS STRAIN
TRIAXIAL AND SQUEEZE TESTS
VICKSBURG CLAY

PLATE 4



SHEAR STRENGTH CORRELATION
TRIAXIAL AND SQUEEZE TESTS
MOUND AND VICKSBURG CLAYS



LEGEND

TRIAXIAL TEST:
- O MOUND CLAY
- ⊙ VICKSBURG CLAY

SQUEEZE TEST:
- Δ MOUND CLAY
- Δ VICKSBURG CLAY

□ UNCONFINED COMPRESSION TEST AVERAGE FOR 15 SOILS

SHEAR STRENGTH

UNCONFINED COMPRESSION, TRIAXIAL AND SQUEEZE TESTS VS CONE INDEX

PLATE 5

APPENDIX A: DERIVATION OF THE SQUEEZE TEST STRENGTH EQUATION

1. The basic derivations of the squeeze test strength equation were taken from the works of Dr. Leo Jurgenson.[3*] Theory of the squeeze test is based upon the Hencky principle of plastic equilibrium[1] and an application of this principle to the case of a plastic body compressed between hard plates presented by L. Prandtl.[6] The maximum shear stress, τ_{max}, which would be constant in the entirely plastic body is

$$\tau_{max} = \sqrt{S_{xz}^{2} + \left(\frac{S_x - S_z}{2}\right)^2}$$

and is the condition of plasticity for this case. As load is applied during the test, flow lines or failure planes are formed which are families of cycloids: $y = a \cos 2\beta;\ x = \mp a\ (2\beta \pm \sin 2\beta + \text{const})$.

2. The stresses are:

$$n_x = \mp\frac{c(L - x)}{a} \pm 2c\sqrt{1 - \frac{z^2}{a^2}} + \text{const}$$

$$n_z = \mp\frac{c(L - x)}{a} + \text{const}$$

and

$$S_{xz} = -c\ z/a$$

3. The constants in the above are determined from the condition that $\int_{-a}^{+a} n_x\,dz = 0$ when $x = L$. The resultant equation of normal stress is

$n_z = \frac{c(L - x)}{a} + \frac{c\pi}{2}$ where L is positive, and $n_z = \frac{c(L + x)}{a} + \frac{c\pi}{2}$ where L is negative. Load, P, on the upper plate is determined by integrating the normal stress over the area:

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* Raised numbers refer to list of references immediately following the main text.

$$P = \int_0^B \int_{-L}^{L} n_z \, dx dy$$

$$P = \int_0^B \int_0^{+L} \left[\frac{c}{a}(L - x) + \frac{c\pi}{2}\right] dx dy + \int_0^B \int_{-L}^{0} \left[\frac{c}{a}(L + x) + \frac{c\pi}{2}\right] dx dy$$

from which

$$P = \frac{cBL^2}{a}\left(1 + \frac{a\pi}{L}\right)$$

and

$$c = \frac{Pa}{BL^2\left(1 + \frac{a\pi}{L}\right)}$$

where

c = shearing strength in terms of load per unit area.

As the thickness, $2a$, changes during the test, the following form is convenient:

$$c = \frac{Pa_o(1 - e)}{BL^2\left[1 + \frac{a\pi(1 - e)}{L}\right]}$$

where

$2a_o$ = initial thickness, and

e = change in thickness divided by $2a_o$.